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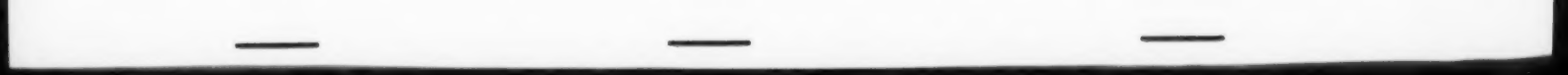

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A BRIEF HISTORY OF THE BAROMETER*

By W. E. KNOWLES MIDDLETON

1. SCOPE OF THIS PAPER

IT is a remarkable fact that the most common means of measuring atmospheric pressure for meteorological purposes is still that devised by Torricelli. There is no fundamental difference between the "Torricellian tube" and the modern "fixed cistern" barometer, the latter being purely a mechanical improvement on the original instrument. Numerous other means of measuring atmospheric pressure have been suggested, but the mercury barometer, in one or other of its many forms, is still the standard for official purposes. It will be my task to present a brief illustrated account of the development of the mercury barometer, and to indicate some of the other ways in which the pressure of the atmosphere has been measured. The literature of barometry is tremendous, and of course no attempt can be made to present a fully documented history.

2. THE MERCURY BAROMETER IN THE SEVENTEENTH CENTURY

Even before 1700, a number of interesting mercury barometers had been invented, of which the wheel barometer of Hooke (1665) is the earliest to differ greatly from the Torricellian tube. This is a siphon barometer—a barometer in which the tube is in the form of a U. If the two mercury surfaces are equal in area in such a barometer, a given change in the height of the mercury column will be divided equally between the two ends, so that the movement of either surface will be only about half as much as that of the mercury in the Torricel-

*A paper read at the Tercentenary Commemoration of the invention of the Barometer, at Toronto, October 19, 1943.

lian type. Hooke was anxious to magnify the motion of the mercury, so he provided a large bulb to accommodate the upper surface, thereby concentrating most of the motion into the lower, exposed arm. (We must presume that the upper level was in the diametral plane of the bulb; a cylinder would have been safer.) A float rested on the exposed mercury surface in the open arm, and a line from this float passed over

FIG. 1—THE TORRICELLIAN EXPERIMENT

a pulley and ended in a counterweight. On the shaft of the pulley was a pointer, which could move over a scale, greatly magnifying the motion of the mercury surface.

Hooke made many observations with his barometer. He had not continued them for long, we may imagine, when he wrote (October 6, 1664) to Boyle:

> I have also ... constantly observed the baroscopical index (the contrivance, I suppose, you may remember, which shows the small variations of the air) and have found it most certainly to predict rainy and cloudy weather, when it falls

very low; and dry and clear weather, when it riseth very high, which if it continue to do so, as I have hitherto observed it, I hope it will help us one step towards the raising of a theorical pillar or pyramid, from the top of which, when raised and ascended, we may be able to see the mutations of the weather at some distance before they approach us, and thereby being able to predict, and forewarn, many dangers may be prevented, and the good of mankind very much promoted.

Hooke was not the last man to imagine that he had found the secret

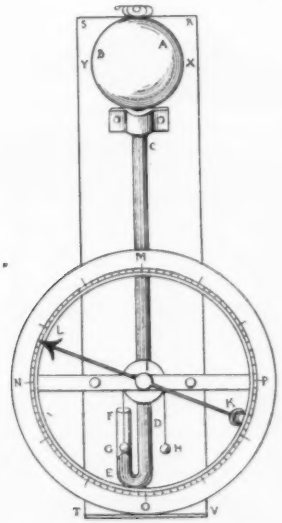

Fig. 2.—The wheel barometer of Robert Hooke

of forecasting; but his hopes shortly lost their bloom, for he wrote again three months later (December 13, 1664):

I have lately observed many circumstances in the height of the mercurial cylinder, which do very much cross my former observations; for at this very time the quicksilver is as high as I have a long time observed it, and I don't remember that it has been higher: it has risen a little for these four or five days, and has continued so, notwithstanding the variety of winds, and the multitude of rain, that has lately fallen; and, I think, it rises a little yet, but it is but little. I have taken notice also of two or three other very odd particulars lately in it, which have crossed several other observations.

The "two or three other very odd particulars" provide occupation for a great many meteorologists, even two hundred and seventy-nine years later.

Others were interested in increasing the scale of the barometer, and by 1672 Huyghens had devised an instrument in which the short

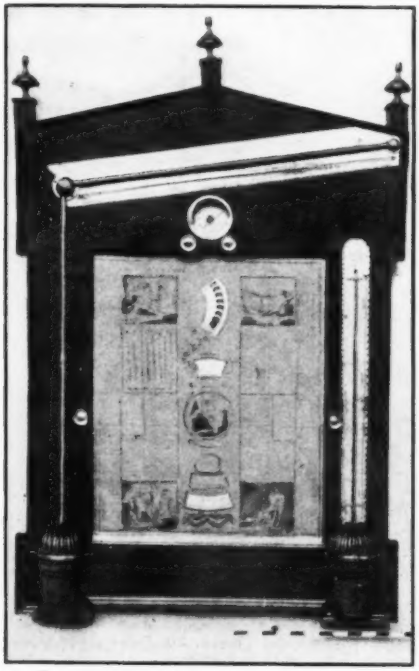

Fig. 3.—DIAGONAL BAROMETER (18th Century)
Courtesy of the Science Museum, South Kensington.

arm of the siphon barometer was continued upwards, enlargements being provided at the levels of the mercury surfaces. The tube attached to the short arm was filled with a much lighter liquid (dilute nitric acid) and the reading was taken at the upper surface of this.

An entirely different approach to the problem is preserved in the

diagonal barometer, ascribed to Sir Samuel Morland and supposed (on what authority I do not know) to have been invented about 1670. In this instrument the upper part of the tube is bent over at an angle, so that it is not far from the horizontal; and a small increment in the height of the mercury is represented by a large movement along the tube. The instrument shown in the photograph is a particularly fine example constructed about the middle of the eighteenth century, and in addition to the barometric tube, has a thermometer, a hygroscope, and a perpetual calendar.

Samuel Morland is also supposed to have invented a barometer in which the tube containing the mercury hung on a balance, its free end dipping into a cistern. I have been unable to find original references to either of Morland's barometers, but they are mentioned by all the authorities.

Another *desideratum* was to have the barometer portable, so that it might be used on shipboard, or on a journey. Some time previous to 1688 it had been discovered that air will pass through the pores of wood, for in that year there was published in Amsterdam a delightful little "Treatise on barometers, thermometers, and hygrometers," which contains a description of a barometer with a closed wooden cistern, obviously more portable than that of Torricelli. Incidentally, this book shows quite clearly how fashionable science had become in the latter part of the seventeenth century; instruments were often decorated to match the prevailing styles of furniture, as shown in many of the plates of the "Treatise." Princes maintained laboratories, noblemen and courtiers took delight in making and witnessing all manner of experiments, often out of mere idle curiosity, but sometimes (as in the case of the Hon. Robert Boyle), with great originality and talent. Fashion is a motive force often neglected by historians in their preoccupation with cause and effect. Science was fashionable in the years after 1650, and it is likely that much of its remarkable progress in that period is due to this fact.

Anyone who has had to carry mercury barometers about knows that the instrument is inconveniently long. In 1688 Amontons described a "folded up" barometer, in which the pressure of the air was balanced by more than one column of mercury. The intermediate tubes contained air, the space above the mercury at the closed end

was, of course, a vacuum. Such an instrument would be hard to fill, and would be affected by temperature in a complicated manner.

It was soon found that ordinary mercury barometers were of little use at sea, because the motion of the ship caused the mercury to pump violently up and down. In 1695 Amontons suggested the use of a conical tube, the diameter increasing downwards, with no cistern, but it is hard to believe that such a device was very satisfactory.

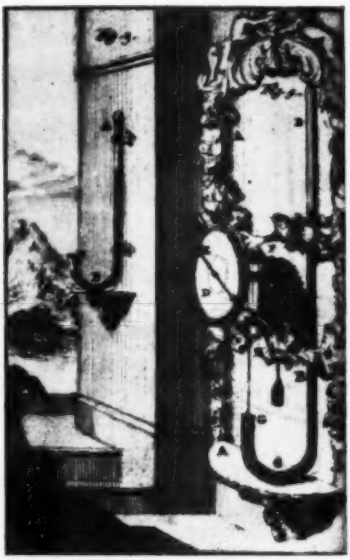

Fig. 4.—Decorated barometer, after d'Alencé

The contrivances which we have described up to this time can scarcely be said to have carried the accuracy of barometry very far. The various attempts to obtain an open scale all introduced errors greater than those they eliminated, because of the effects of capillarity and temperature. Hooke's wheel barometer was by far the best of them, and indeed survived almost to the end of the nineteenth century in popular use. Just at the end of the seventeenth century, it occurred

to Derham (1698) and to Gray (1698) that instead of trying to increase the movement of the mercury surface, it would be better to use the ordinary barometer tube and to devise a more sensitive means of reading the instrument.

In Derham's construction an index is moved up and down by a rack and pinion. To the pinion is attached a hand, moving over a graduated circle. Obviously a very large magnification could be obtained in this way, but we may reasonably ask whether the accuracy of gearing in 1698 was high enough to make it a real improvement.

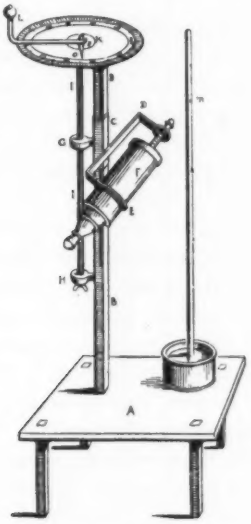

Fig. 5.—GRAY'S BAROMETER

In Gray's instrument the barometer tube was observed through a compound microscope mounted on a vertical screw, exactly as in the modern cathetometer. The inches and tenths are read off on a vertical scale, and finer parts from an index attached to the screw and moving over a circular dial. The accuracy of this arrangement, of course, depends directly on that of the screw; but even in 1698 it must have been far better than the current practice of estimating the

height of the mercury by comparison with a scale standing beside the tube.

3. Eighteenth-Century Mercury Barometers

We see that by 1700 a good deal of progress had been made in the improvement of mercury barometers. The importance of barometry was realized, as is seen in the following passage written by Amontons in 1704:

> Among the physical discoveries of the last century that of the barometer, or the means of measuring the weight [*poids*] of the atmosphere, may well hold first place.

A year later he mentioned (as if it were well known) the practice of putting words on the scale of a barometer, indicating weather. Barometers for popular use are still provided with such legends, some of the most recent having on the dial a great deal of information, amounting to a condensed treatise on single-observer forecasting. I need scarcely say that professional meteorologists do not take these prognostics too seriously.

Barometers with expanded scales continued to appear. Thus J. Bernoulli is said to have suggested the "square barometer" about 1710; an instrument in which the open limb takes the form of a narrow horizontal tube. In 1733 Rowning published in the *Philosophical Transactions* "A description of a barometer, wherein the scale of variation may be encreased at pleasure." This was really a form of weight barometer, of interest only as another manifestation of the desire to avoid fine measurements.

Much more significant improvements were, however, on the way. In 1733 Beighton gave a good description of the process of boiling the mercury in the barometer tube, ascribing it to one Charles Orme, presumably an instrument maker. This was of capital importance for the permanence of the calibration, since it removed air and moisture that would otherwise be trapped in the mercury and on the walls of the tube. At about the same time the idea of a leather bag to form the bottom of the cistern occurred to some unknown artisan or philosopher; a screw acting on the bag could be used to reduce the volume of the cistern until the entire instrument was full of mercury, rendering it much less liable to damage in transport. Arrangements for maintaining a constant mercury level in the cistern were not, however,

provided. Brisson, in 1755, suggested a barometer having an overflow arrangement in the cistern, so ensuring that the level of the mercury was always the same. More mercury than was needed was poured into the cistern and the excess ran out into another vessel through a small hole. This of course was unhandy and not a very good solution of the problem.

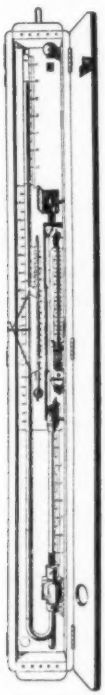

FIG. 6.—DE LUC'S SIPHON BAROMETER

It was at about this period that De Luc became interested in meteorology. This celebrated scientist realized that all the barometers in use at that period were unsatisfactory in one way or another. He was especially interested in having a portable barometer, so that it might be possible to ascend mountains with it and find the law

relating the pressure and the height above sea level. It was probably about 1755 that he devised the siphon barometer with which he made so many observations on the mountains of Europe. This barometer had two scales, each starting from a point about the middle of the barometer; one increasing upwards, the other downwards. When both scales were read against the mercury column in the two limbs of the barometer, and the readings of the scale added, the true height of the mercury column could be obtained. De Luc also realized that it was necessary to correct the height of the column for the effect of temperature, and provided a thermometer attached to his barometer for the purpose of measuring the temperature of the instrument. From that day to this all barometers having any pretension to scientific accuracy have been provided with such thermometers.

In order to make it portable, De Luc's barometer was provided with a tap at the bend in the siphon tube. This isolated the mercury in the longer limb, and when the barometer was to be transported it could be tilted somewhat, filling the longer limb with mercury. The valve then being closed, the mercury could not shake about in the tube with danger of breakage.

In a short study such as this we have not time to detail all the many improvements and re-inventions that are to be found in the literature. Several improved forms of wheel barometer were devised, differing from that of Hooke chiefly in the sort of bearing used for the wheel and other purely mechanical details. Towards the end of the eighteenth century several recording siphon barometers were devised, of which the earliest was probably that due to Cumming, made in 1766 and described by Luke Howard in his book on the Climate of London. No picture of this instrument is available, but it would seem that a float on the open limb of the siphon barometer carried a pencil which made a trace upon paper fastened to a revolving disc. A somewhat different form of recording barometer was designed about 1777 by Baudou. In this, a siphon barometer was attached to a large semi-circular balance beam. When the atmospheric pressure changed, it shifted mercury from one limb of the barometer to the other, thus altering the equilibrium of the beam and causing an attached pencil to move on a travelling chart. This was an elementary

weight barograph. Another weight barograph was described in 1791 by McGuire.

This brings us to the end of the eighteenth century. We shall now retrogress in time and consider some of the other barometers, not containing mercury, devised before the year 1800.

4. Early Barometers Not Containing Mercury

The earliest attempt to measure the pressure of the air by means other than the mercury column seems to have been made by the Honorable Robert Boyle in 1666. In that year he published in the *Philosophical Transactions*, "An Account of a new kind of baroscope, which may be called statical; and of some advantages and conveniences it hath above the mercurial." This instrument consisted of a balance having at one end of its beam a large, light, glass globe; and on the other end a small weight to counterpoise it. The volumes of the globe and the weight being greatly different, the buoyancy of the air on the globe would be much greater than upon the weight and therefore, if the air pressure increased, the globe would appear to weigh less and the end of the beam to which it was attached would move upward. Similarly, if the air pressure decreased, the globe would move downward.

It will be immediately obvious that such an instrument measured not the pressure but the density of the air; and since the density depends not only on the pressure but also on the temperature, the indications of the instrument would depend very largely on whether the air was warm or cold.

It is interesting that Boyle suggested the use of this instrument for measuring altitudes.

The unusual-looking "baroscope" of Caswell (1704) was fundamentally similar to that of Boyle, but it used the buoyancy of water as the counterbalancing force.

Boyle's "statical baroscope" is an example of an instrument that was intended to measure pressure but was greatly affected by temperature. An early instrument designed to measure temperature, the air thermometer, was, on the other hand, also affected by the pressure of the air. The air thermometer is a very easily constructed instrument consisting merely of a good-sized bulb connected to a tube dipping into

some liquid. If the bulb becomes cooler the air inside it contracts and the liquid rises in the tube; if it becomes warmer, the air expands again and the liquid falls. Obviously the level of the liquid in the tube will also depend on the pressure of the air on the surface of the liquid in the vessel. Some time before 1700 it occurred to Robert Hooke, the inventor of the wheel barometer, that the air thermometer could be used as a barometer if the effect of temperature was corrected for, by using it in conjunction with another kind of thermometer not affected by pressure; for instance, an ordinary spirit thermometer. According to the astronomer Halley, who wrote about Hooke's barometer in 1700, this had been used a good deal for taking observations on ships at sea where the ordinary mercury barometer was not suitable because of the constant motion of the ship. Halley refers to it as a marine barometer. In 1724 Desaguliers suggested that the instrument could be greatly improved by enclosing the air bulb in a large vessel containing water at a constant temperature. In this form it could possibly be made fairly accurate.

Hooke's "Marine barometer" was re-invented in 1818 by Adie, under the name of sympiesometer, and became a common ornament of nineteenth century drawing-rooms.

If the pressure of the air will support a column of mercury about 30 inches high, it would naturally be expected that it would support a much higher column of water, since mercury is more than 13 times as heavy as water. Some time before 1660 Otto Von Guericke made a water barometer consisting of a large tube more than 30 feet long dipping into a tub of water. Near the bottom of the tube there was a tap and when the tube had first been filled with water it was inverted into the tub and the tap opened. The water in the tube then sank to a certain level which could be observed through the upper part of the tube, made of glass for that purpose. Von Guericke found that the pressure of the atmosphere, as indicated by the height of the water, fluctuated from day to day and made a study of its variation in connection with the changes of the weather. It is said that a sudden drop in the pressure enabled him to forecast a severe storm in 1660.

While these barometers did not need mercury, however, they still made use of various liquids. A completely dry barometer was first suggested in 1758 by Zaiher. This consisted of a hollow exhausted cylinder having movable ends kept apart by an internal spring. If the

pressure of the atmosphere increased, the spring would be compressed and the ends of the cylinder would move closer together; if it decreased they would move further apart.

This idea was almost a century ahead of its time. To find its practical realization we must jump to 1848, that remarkable year when all Europe was full of new ideas and old ideas in new dresses. In 1848 Vidi invented the well-known aneroid barometer, carrying out Zaiher's eighteenth century idea by the simple device of a corrugated metal box, exhausted of air and kept from collapsing by a spring. We shall return to this very useful instrument later.

In 1724 Fahrenheit suggested the use of the thermometer as a barometer. It had been noticed that the boiling point of water varied with the atmospheric pressure, being slightly higher when the pressure was high. The temperature indicated by a thermometer with its bulb in boiling water could therefore be used as an index of pressure. About 1765, De Luc devised an apparatus with which he made many experiments on the variation of the boiling point of water with altitude above sea level. Finally, in 1817, Wollaston devised the modern form of this apparatus which is now called the hypsometer, or height-measurer, in which the bulb is exposed to the steam only, and not plunged in the boiling water. It is found that the temperature of the steam is steadier than that of the water and indeed the temperature of the latter depends on the depth below the surface at which it is measured, since the pressure due to the water above the thermometer bulb must be added to the pressure of the air on the surface.

5. Nineteenth Century Mercury Barometers

The early years of the nineteenth century were marked by an astonishing number of modifications to the barometer; some of them real improvements, some of them re-inventions of discarded mechanisms, some completely trivial. One of the earliest was that of John Gough (1807) who suggested moving an ivory piston up or down in the open limb of a siphon barometer, in order to bring the mercury surface to the level of a graduation on the glass, which was at the zero of the scale. About 1810, although the exact date is not known, a French mechanic called Fortin invented the simple and elegant mechanism which has been used on many thousands of barometers

and is still in use to-day. In Fortin's barometer, a leather bag, movable by a screw, forms the bottom of the cistern. When the barometer is to be read, the surface of the mercury is raised by turning the screw until it just touches a fixed ivory point, which represents the zero of the scale.

It is strange that nothing whatever seems to be known about

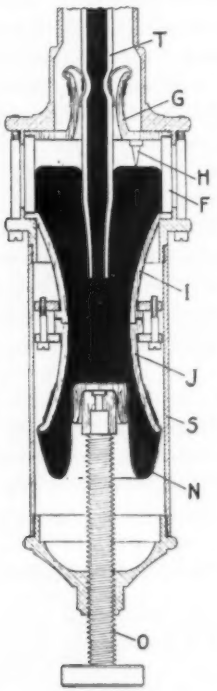

Fig. 7.—FORTIN BAROMETER CISTERN (modern form)

the inventor of this excellent device. I have been entirely unable to find any biographical details about Fortin, and I should be very grateful if any of my readers could supply this deficiency.

It was at about this time that it began to be generally realized that the scales of most of the barometers then constructed (though not, of

course, the Fortin instrument) were really not correct, since as the mercury rose or fell in the tube it fell or rose at the same time in the cistern to an amount depending on the relative sizes of cistern and tube. An author writing in *Nicholson's Journal* in 1811, over the initials "L.O.C.," pointed out that the matter could be corrected if the scale was not in real inches, but in units of something less than an inch. This is actually the principle used at the present day in most of the barometers used at ordinary meteorological stations in the British Empire. At this time, however, it did not appear as a good solution to our author, who preferred the use of the siphon barometer with a sliding scale, so that the zero of the scale could be placed opposite the level of the mercury in the lower limb.

A variation of this last idea, applied to a cistern barometer, led to one of the finest nineteenth century barometers, the movable scale barometer of Newman. Several of these barometers were constructed between 1835 and 1840 and at least three of them have become famous because they were sent, on the instructions of the British government, to Toronto, to St. Helena, and to Bombay. The barometers at Toronto and Bombay are still in good working order. The Toronto one, being slightly the older of the two, is probably the oldest barometer still in working condition; at the most recent comparison its correction to the Washington standard at 30 inches of mercury was exactly zero. The Newman barometer consists of a large cistern of iron and glass into which dips a tube having an internal diameter of approximately half an inch. The scale is attached to a long square brass rod which can be racked up and down inside a square brass tube forming part of the frame of the barometer. The lower end of the brass rod is turned to a cylinder and carries an ivory point, and the tip of this ivory point is at the zero of the scale; that is to say, the mark 30", for example, is exactly 30 inches from the ivory point. It will be seen that if the ivory point is moved down so that it just touches the mercury, the scale may be used to obtain a direct reading of the height of the barometric column. A thermometer for measuring the temperature of the mercury has its bulb in the cistern. It will interest a Toronto audience to know that Newman No. 33 was in use at Toronto almost continuously from 1840 to 1939 when it was "pensioned off" because it was felt that so valuable an instrument should not be used for routine observations.

The principle of the movable scale with the point at the lower end was adopted in 1837 for a large barometer fitted up at the apartments of the Royal Society. This was provided with two large tubes, one of crown-glass, one of flint glass, dipping into the same cistern. The scale was between them and terminated in an agate point. The provision of the two tubes was for the study of any chemical action between the glass and the mercury, though it does not seem to be recorded whether anything was observed.

Photography was invented at about this time and the new art was very soon applied to scientific purposes. In 1847 Brooke and Ronalds both described barographs using photographic registration. The arrangement devised by Ronalds was fundamentally the same as that of the famous Kew photographic barograph, which was in use at many stations, including Toronto, for more than half a century. In this instrument the projected image of the top of the mercury column of a cistern barometer is photographed on a piece of bromide paper wrapped around a rotating drum. A special arrangement compensates the instrument for temperature.

The well-known Kew marine barometer used so extensively on British ships for the past 90 years was first described by the Meteorological Committee of the British Association in 1853. The fundamental problem in barometers for use at sea is to damp out the pumping of the mercury due to the motion of the vessel. In the Kew barometer, which has a non-adjustable iron cistern, this problem is solved by making the middle portion of the tube very narrow in bore, so that the mercury takes an appreciable time to go through it. This construction really causes the barometer to give an average of the atmospheric pressure for several minutes just past, and reduces the motion of the mercury surface to negligible proportions. Since there is no adjustment in the cistern this barometer is one of that class of instruments in which the mercury level in the cistern varies with atmospheric pressure, and in consequence it is necessary to graduate the scale not in the real units of pressure, but in units somewhat shorter.

Fixed-cistern barometers essentially similar to the Kew marine barometer except that the tube was not constricted to the same extent, have been very largely used at land stations throughout the British Empire. On the continent of Europe, on the other hand, an

improved form of the siphon barometer is preferred. In the United States a modern form of the Fortin barometer has been used for official purposes up to the present time, but interest in the fixed-cistern type of barometer is now becoming manifest.

There have been many constructions of both these types of barometer in the last 90 years but none of them are fundamentally very different from the prototypes.

The last half of the nineteenth century saw the invention of a number of weight barographs, some of them instruments of great excellence. The first of these was that of Secchi, described in 1857. Others were invented by Wild, 1862 and 1870; and by Sprung in 1878. All of these barometers operate on similar principles, a barometer

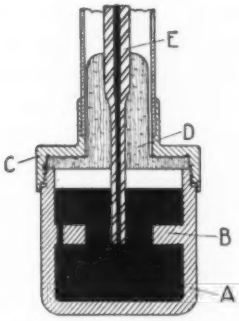

Fig. 8.—KEW BAROMETER CISTERN

tube being hung from one arm of a balance and dipping into a cistern. Some form of variable or moving weight is used to balance the variations of the atmospheric pressure acting on the upper surface of the tube. The motions of the weight are recorded by a pen or pencil. The weight barograph is probably the most fundamentally accurate form of mercury barograph, and a number of examples of the type due to Sprung were installed at various stations in various parts of the world. At about the end of the century, a successful barograph of this type was constructed by Marvin of the United States Weather Bureau and was in use for many years.

A completely different type of weight barograph is that due to

King, constructed in 1862. In this instrument a very large barometer tube floats in a deep cistern, the pressure of the air on the top of the tube being mainly counterpoised by a weight acting on a chain passing over a large pulley. The tube sinks in the cistern until the buoyancy of the mercury on the submerged parts of the tube is equal to the uncompensated force, and since this varies with variations in the atmospheric pressure, a record can be made by means of a pen attached to the chain. The success of a barometer of this type obviously depends largely on the excellence of the workmanship.

Another type of barograph is based on the siphon barometer. One

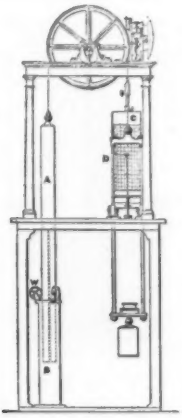

Fig. 9.—KING'S WEIGHT BAROGRAPH

can easily understand that the presence in the open limb of this barometer of an easily accessible mercury surface moving under the variations of the atmospheric pressure suggested to many designers the possibility of attaching some sort of recording mechanism to a float moving with the mercury surface. The earliest type of barograph of which we have certain knowledge is a siphon barograph, the clock barometer of Cumming above referred to, and since that time there have been a large number of different designs. It was soon found that the friction of a pen or pencil on a moving chart was sufficient to cause considerable inaccuracy in the record unless great care was taken with the design, and in 1780 Changeux thought of having the record

intermittent and produced by means of a hammer striking a pencil which most of the time was free. Variations on this barometer were constructed by Kreil in 1841, by Bryson in 1844, and by Milne in 1857. It was not very satisfactory to have the record intermittent and in the last half of the nineteenth century several attempts were made, more or less successful, to make a siphon barometer give a continuous record. Most of these used electrical means of moving the pen, the best of them probably being those of Regnard (1857) and of Hough (1865). That of Hough also printed the pressure in figures once an hour on a tape, as did that of Theorell, devised in Sweden in 1869. In all of these instruments the motion of the mercury or of a float floating in it established electrical contacts which, through the intervention of relays, caused some sort of motor to move the pen.

Finally, at the beginning of the twentieth century, instrument making had so improved that it was found possible to design a purely mechanical siphon barograph of great excellence, which was due to W. H. Dines. This instrument goes back to the original idea of Cumming in the eighteenth century, but several very ingenious features of design render its performance highly satisfactory. One of its most interesting features is that it is compensated for temperature by means of a bell-shaped float with a certain definite amount of air left underneath it.

6. The Modern Metallic Barometer

We mentioned before that Vidi invented the aneroid barometer in 1848. The external appearance of this instrument must be familiar to almost everyone, in its decorative dress as a "weather-glass" with various words on the face of it, indicating the kind of weather that its readings are supposed to prognosticate. I have no doubt that many of my audience will be interested to know what the interior of such an instrument looks like (Fig. 10). They will note the chamber C, composed of two flat corrugated metal diaphragms soldered together at their edges. This chamber is exhausted of air and would collapse if it was not held up by the thick spring D, acting on a knife edge G which passes through a post projecting from the top surface of the chamber. To the spring is attached a lever H and to that in turn a series of magnifying levers, J, K, L, M, the last of which pulls a chain N, which

is wrapped around the shaft of the pointer. This general construction has not varied very much for a long time except that some very recent instruments have a slightly simpler system of levers, but the accuracy and durability of the instrument has constantly improved and for this we have to thank not only the skill of the instrument makers, but also the ingenuity of the metallurgists who have devised better and better metals for making the aneroid chamber, until at present these chambers are often made of a wonderful new alloy called beryllium bronze, an alloy with many interesting properties, not the least of them being the habit of going back to exactly its original form after having been bent

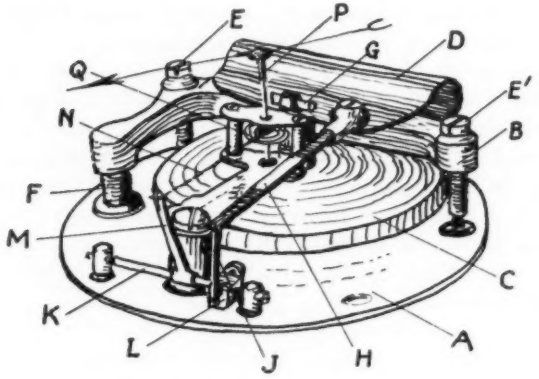

Fig. 10.—Aneroid mechanism

or stretched a little. It may be a surprise to many of my audience to realize that most metals do not generally do this, but such is in fact the case and this is usually the limiting factor in the accuracy of aneroid barometers.

It is comparatively easy to make an aneroid barometer into a recording instrument because we only have to put a pen on the tip of the pointer and provide a revolving or moving chart under the pen to make it give a record of the variations of the atmospheric pressure. Of course the levers are arranged in a different way and the proportions of the instrument are very different. Even the chamber becomes a bellows made of metal instead of a flat capsule. Instruments

of this sort are to-day used at practically all meteorological stations in order to keep track of the variations of the barometer between observation times .

7. Conclusion

By way of conclusion to this brief and incomplete history, I shall mention some of the barometers in use at the present day at Canadian

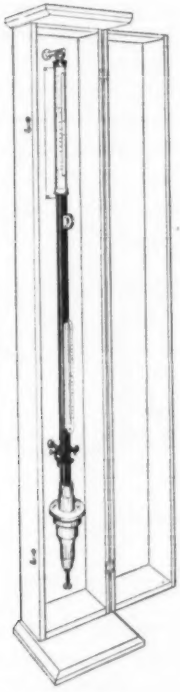

Fig. 11.—Patterson barometer in cabinet

meteorological stations. At some of our stations the Kew barometer, mentioned before, is still in use, and this is a very excellent and convenient barometer for ordinary observers, because nothing has to be done to the cistern when it is to be read—it is only necessary to tap the instrument, set the vernier slide, and then read the vernier.

Unfortunately the Kew barometer in its original form is somewhat liable to damage in transport and numbers of these barometers were broken while getting them to remote stations. In an attempt to devise an instrument easier to transport, while retaining the advantages of the Kew barometer, our Chairman of this meeting, Dr. J. Patterson, devised a type of barometer which acts as a fixed cistern barometer when in use, and as a movable cistern instrument while being transported. For transport, a screw at the bottom of the barometer is screwed up, pushing a steel plunger against a leather bag, and reducing

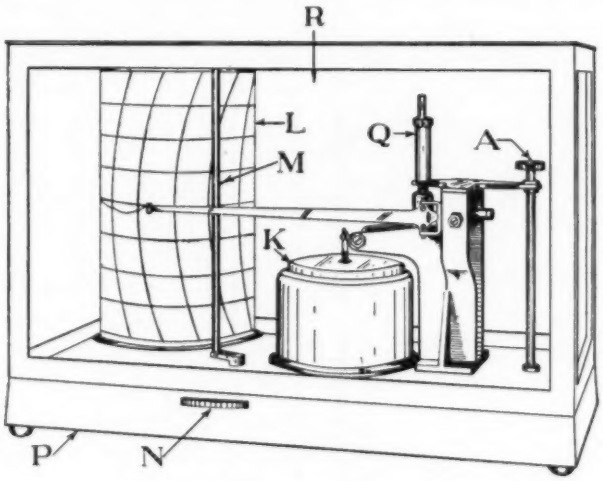

Fig. 12.—Canadian aneroid barograph

the volume of the cistern until the cistern and the tube are full of mercury, so that there can be no splashing of mercury in the cistern with the resulting possibility of damage. When it has been installed at a station, the screw is removed and the steel plunger falls to its lowest point. The volume of the cistern is then quite definite and the instrument acts just like the Kew barometer.

For inspection purposes a Fortin barometer of a modified type is used in Canada. This has a somewhat greater accuracy of reading than the fixed cistern barometer, a desirable feature in a barometer

to be used for comparison purposes, and it is also very easily portable.

The aneroid barograph at present made in Toronto and used in the Canadian service is much like the instrument described above, but the sensitive bellows is considerably larger and of improved construction.

Finally I wish to refer briefly to the improved electrical weight barograph which was constructed in the workshop of the Meteorological Service, and is in use in Toronto. The general principle of this instrument is precisely the same as that of Sprung's barograph referred to above, but refinement of design and construction has considerably increased the accuracy of this instrument until it is probably the most accurate barograph yet constructed. It also prints the barometric pressure on the edge of the chart once an hour.

I believe that a Toronto audience may take a certain amount of justifiable local pride in considering that the history of the barometer would not be quite complete without reference to their city.

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A SEMI-AUTOMATIC GRAPHICAL INTENSITOMETER FOR THE REDUCTION OF MICROPHOTOMETER TRACINGS

By C. S. Beals

Introduction

THERE have been in recent years two general approaches to the problem of eliminating or reducing the drudgery involved in photographic spectrophotometry. The first is represented by the instruments designed by Minnaert and Houtgast[1] and by Williams and Hiltner,[2] which produce an intensity curve of the spectrum directly from the photographic plate without the intermediary of the ordinary microphotometer tracing.

A second solution of the problem makes use of the usual microphotometer tracing and aims at devising means for its rapid graphical reduction. Successful instruments, all involving similar principles, have been developed for this purpose by Haberl,[3] Perepelkin,[4] Hemmendinger,[5] Pannekoek and Koelbloed,[6] Dunham,[7] Wouda,[8] and Langstroth.[9]

In choosing the type of instrument best fitted to the needs of this observatory the following qualities were considered: (1) accuracy, (2) speed, (3) simplicity of construction and ease of repair and maintenance, (4) adaptability to small dispersion spectra covering a great range of wave-length, and (5) ability to make use of the great body of stellar spectrograms in the collection of the observatory, most of which have strip or spot calibrations imposed upon them.

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[2] *Pub. Obs. Univ. Mich.*, vol. 8, p. 45, 1940.

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The direct intensity instrument of Minnaert and Houtgast, making use as it does of templates cut to the form of the calibration curve, is well adapted to the analysis of large dispersion grating plates of the solar spectrum but would be less convenient for small-scale spectograms where numerous calibration curves would have to be constructed to cover a single plate. The Williams and Hiltner instrument which also produces intensities directly from the plate, was especially designed to deal with changes in wave-length of the spectrum under analysis but requires a special logarithmic type of calibration which is not available in most of the Victoria plates. Its relatively elaborate electrical and mechanical design is also somewhat disadvantageous for an observatory without extensive laboratory and workshop facilities. In the matter of speed and accuracy it is difficult to make significant comparisons between different instruments. Theoretically, all are of equal accuracy, while the relative speeds of working will depend upon the nature of the task undertaken.

The final decision to construct a purely mechanical instrument for the reduction of microphotometer tracings, along the lines of those of Hemmendinger, and Pannekoek and Koelbloed, was governed largely by (3) and (5) above, and the completed instrument is described in this paper. No originality is claimed for the general principles on which it operates but the details of the design have proved so satisfactory in practice and have resulted in such a gratifying increase in the output of spectrophotometric measurements that it has seemed worthwhile to publish a brief description. Many of the most valuable features of the instrument are due to the maker, Mr. S. S. Girling, who has shown exceptional ingenuity and skill in solving the various problems of design and construction.

General Principles of Construction and Operation

The working of the instrument can best be understood by reference to the illustration of Fig. 1. A calibration curve C, with galvanometer deflections as ordinates and direct (not log.) intensities as abscissae, is drawn on a ground glass plate G, illuminated from below by a lamp and condenser. The ground glass screen is mounted on a carriage which can be moved freely right and left by the operator using the handle H. The upper surface of the condenser which is just below

the ground glass screen has stretched across it a fine wire which casts a shadow on the screen in the axis of ordinates and acts as an index as indicated by the letter *I*. This index, subsequently referred to as the vertical index, remains stationary and does not partake of the right

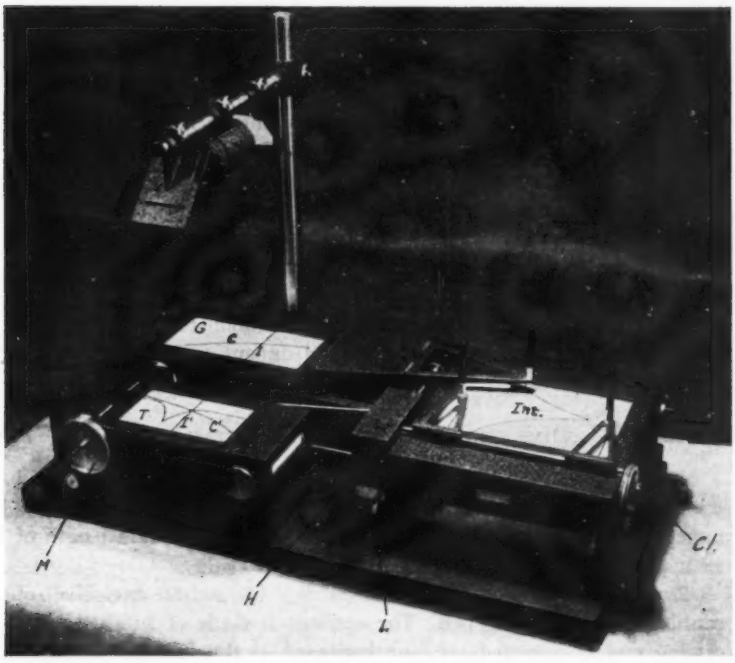

Fig. 1.—Photograph of Intensitometer.

and left hand motion of the ground glass screen on which the calibration curve is drawn.

With the aid of a lens and two 45° mirrors the images of the calibration curve and the vertical index are projected upon a microphotometer tracing *T* which is slowly moved from right to left by means of a motor and speed reducer. As may be seen from the illustra-

tion the projected calibration curve C' is reversed right to left by the action of the mirror-lens system.

To work the machine the operator, by means of the handle H, continuously adjusts the position of the moving carriage so that the calibration curve always intersects the vertical index at the same point as the tracing T. The technique of operation thus consists in keeping these three lines intersecting at one point.

Attached to the moving carriage is a pen which bears upon a paper strip moving synchronously with the tracing by means of a system of gearing which connects the two. From this it may be seen that for every ordinate (galvanometer deflection) indicated by the intersection of I and T there corresponds an abscissa (intensity) indicated by the position of the pen on the moving paper strip. The intensity curve *Int.* is thus continuously drawn by the pen as a result of the action of the operator in keeping the calibration curve and the tracing intersecting the index at the same point.

The above principles of operation are common to all instruments of this type. Details of construction and dimensions are included in the following notes.

Dimensions and Technical Details

1. *Ground Glass Screen.* Dimensions $6 \times 11 \times \frac{1}{8}$ in. ground with fine carborundum. The screen has etched upon one edge of its upper surface an intensity scale of 100 divisions covering a length of 10 inches. (Not shown in illustration.)

2. *Moving Carriage.* Dimensions 9×14 inches exclusive of cantilever arm carrying pen. The carriage is made of an aluminium casting and is mounted on four hardened steel wheels of one-inch diameter with four individual axles of $\frac{1}{4}$-in. diameter. Longitudinal facings of brass are used to maintain alignment of the carriage and save wear on the aluminium. A hinged frame covers the top and outlines an area of the ground glass screen 5 in. $\times$ $10\frac{1}{2}$ in.

The cantilever arm carrying the pen is 14 inches long and hinged in the centre as shown in the illustration, the hinged part together with the pen providing the correct pressure for writing.

3. *Tracks for Moving Carriage.* The tracks consist of two iron castings of general dimensions 22 inches long and $5\frac{1}{2}$ inches high,

with three longitudinal flanges cast on their inner surfaces and accurately machined. The lower of these flanges is for the purpose of fastening the track to the base and maintaining its vertical position. The second flange, 3 inches above the base, serves as a flat surface on which the wheels of the carriage roll. The third flange with its inner edge machined 5 inches above the base serves to align the moving carriage in its right and left hand motion. Two adjustable spacers allow for fine adjustments in the distance apart of the tracks.

4. *Condenser.* The condensing lens consists of a single-element plano-convex lens of 6½ inches diameter with its upper plan surface 7/16 inch below the upper surface of the ground glass screen. The lens is mounted on a tube or cylinder 5 inches high.

5. *Wire Index.* The index is of steel wire 0.005 in. diameter mounted directly below and almost in contact with the ground glass screen. It is held by two brass clamps attached to the lens tube which has a rotational adjustment for aligning the wire.

6. *Mirror Lens System.* The two mirrors of plate glass, aluminized on their outer surfaces are 3 in. × 5 in. in size. The lens is the projector element of an old lantern, of 2½ in. diameter and 10½ in. focal length. The mirror lens system is mounted on a standard 27 inches high and 1⅝ inches diameter, with a horizontal cantilever 18 in. × 1 in.

7. *Tracing Transport Mechanism.* Overall dimensions are 15½ in. × 6 in. and 6 in. high. The important parts consist of two wooden spools to take tracings 5 inches wide, with metal end flanges, and two rollers as shown in the diagram of Fig. 2. The tracing is unwound from spool *S1* and winds up on spool *S2*. The actual motion of the paper is controlled by a precision roller R_1 of aluminium 2½ in. diameter and 5 in. long, with contact maintained by a secondary roller R_2 of 1 in. diameter. Pressure between the two is maintained by means of a spring acting on the smaller roller and a lever is arranged to release the pressure for paper adjustments.

The two spools are connected by a chain and sprockets and the necessary tension on the paper is maintained by a spring inside spool *S1* with a suitable ratchet, similar in principle to the spring of an ordinary window blind. A crank for winding up the spring can be seen in the illustration of Fig. 1. The tension on the paper will alter

somewhat during a run, owing to the slightly different angular velocities of the two spools as the paper unwinds from one and winds on the other, but this does not affect the motion of the paper which is entirely controlled by the precision roller.

On one end of the axle of the precision roller is mounted a micrometer head having 500 divisions engraved on its periphery so that linear measurements may, if desired, be made on the tracing. A glass plate is mounted underneath the tracing between the right-hand spool and the precision roller, while a hinged cover comes down over the tracing and holds it flat against the glass, leaving free an area of 4½ in. × 7¾ in.

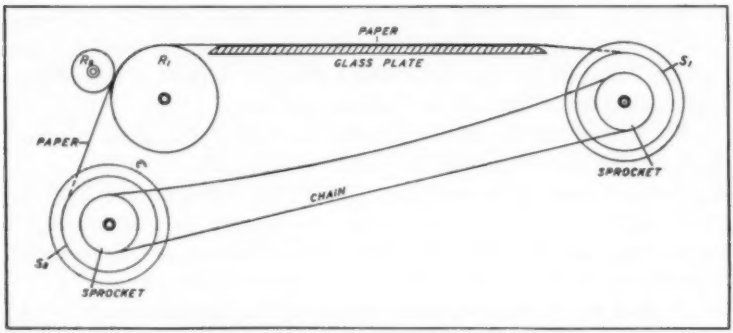

Fig. 2.—Tracing Transport Mechanism.

8. *Paper Transport Mechanism.* The mechanism for moving the paper on which the final intensity curve is drawn is closely similar to the tracing transport mechanism except that the width of the paper strip is 12 in. instead of 5 in. Overall dimensions are 15½ in × 13¾ in. and 6 in. high. Rollers and spools are the same diameter but a double roller is used at R_2 to provide the pressure on the paper. The glass plate under the paper in this case has an intensity scale of 100 divisions etched upon it, precisely similar to the scale on the ground glass screen. A lamp is mounted under the scale so that the intensity of any part of a profile can be read off. It is highly desirable to have a micrometer head in combination with a revolution counter mounted on the end of the precision roller so that accurate linear measurements

can be made in the dispersion co-ordinate *in situ*. This very necessary feature was, through an oversight, left out of the present design.

Two extra pens are provided as shown in the illustration in order to superimpose upon the record, lines corresponding to zero and unit intensity and it is obvious that in a short time a complete co-ordinate system can be drawn on the paper by suitable manipulation of the micrometer head and the three pens.

9. *System of Gearing.* Motion is transmitted by means of a leather belt from a variable speed motor and a 600 : 1 speed reducer to a pulley mounted on the axle of the precision roller of the paper transport mechanism. Three gears of differing diameters are rigidly mounted on the other end of the same axle. According to the ratio desired, these gears engage in turn with one of three sliding gears mounted on a splined shaft. The ratios may be changed by use of the gear shift lever *L*. The splined shaft transmits its motion to the precision roller of the tracing transport mechanism by means of two spiral gears at right angles with a reduction ratio of 1 : 2. Bevel gears, being difficult to cut accurately, are unsuitable for this purpose. The ratios available as between tracing and paper are 1 : 1, 1 : 2, and 1 :4 and these ratios have been found to fulfil satisfactorily all requirements in the work so far carried out. Clutches are provided at *Cl* and *Cl'* so that either the tracing or the paper can be freely moved by hand for purposes of examination or measurement.

10. *Base.* The base of the instrument is an iron casting 21 in. × 39 in. × 2 in. suitably shaped to provide the necessary rigidity without excessive weight. A hole of 6 in. diameter is provided to admit the light from a 100-watt projection lamp to the condenser. A suitable mounting for the lamp as well as a light-proof housing is provided underneath the base.

11. *Manual and Foot Controls.* Manual controls for both right and left hands are provided in order to govern accurately the motion of the carriage bearing the calibration curve. The handles consist of bakelite discs of 1⅞ in. diameter, one of which is clearly shown at *H* in front of the instrument. A shaft from this handle transmits its motion by means of a 1¼-in. gear to a toothed rack attached to the moving carriage. The shaft for the left hand control is connected to the direct shaft by means of a bevel gear. This shaft can be seen

sloping down to the left behind the tracing transport mechanism. The handle itself is not visible. Arm rests are provided and are very important for accurate work although they are not shown in the illustration.

The speed of the motor drive is controlled by means of a foot rheostat originally built for a Singer Sewing Machine. The variable speed A.C. motor is 1/10 h.p. with a maximum speed of 10,000 r.p.m.

The Instrument in Use

In use the instrument has exceeded expectation in the ease and rapidity of its operation. One very attractive feature is the ease with which the calibration curve can be constructed. Owing to the nature of the optical system the ordinates (galvanometer deflections) can be transferred directly from the tracing to the ground glass screen by projection, without the necessity of making measurements, while the abscissae are given directly by the intensity scale etched on the surface of the ground glass screen. It is thus only necessary in plotting a point on the curve, to move the carriage until the desired intensity value on the scale is cut by the vertical index and then, placing a pencil on the index line, move it up or down until its shadow falls on the appropriate density mark on the tracing. After the points are plotted the screen can be lifted out and taken to a drafting table for drawing the curve.

The intensity records can be used directly for obtaining equivalent widths without alteration, but if profiles are desired it is necessary to "rectify" the record by reducing the continuous spectrum to unit intensity over the wave-length range of the profile. This is easily done *in situ* with the aid of the intensity scale etched on the glass plate of the paper transport mechanism or with the aid of an auxiliary transparent scale which has been constructed and incorporated into a table built for the purpose in a nearby room. The paper is sufficiently transparent for the scale underneath the record to be clearly seen when illuminated from below. It has been estimated that the time required for obtaining equivalent widths without rectifying has been reduced to 1/10 and that a rectified line profile can be completed in from one-fifth to one-seventh the time required by the older method.

As an indication of the accuracy obtainable with this machine as compared with the usual method of making micrometer settings on the tracing and reducing the individual points with the aid of a logarithmic calibration curve, a section of the spectrum of P Cygni on a 2nd order grating plate with a dispersion of 6.8 A per mm. was chosen, which contains the line λ5875 of helium I. Profiles were derived by the two methods and the results are indicated in Fig. 3. The profile obtained with the intensitometer is drawn as a continuous line and the filled circles indicate the profile obtained by the older method.

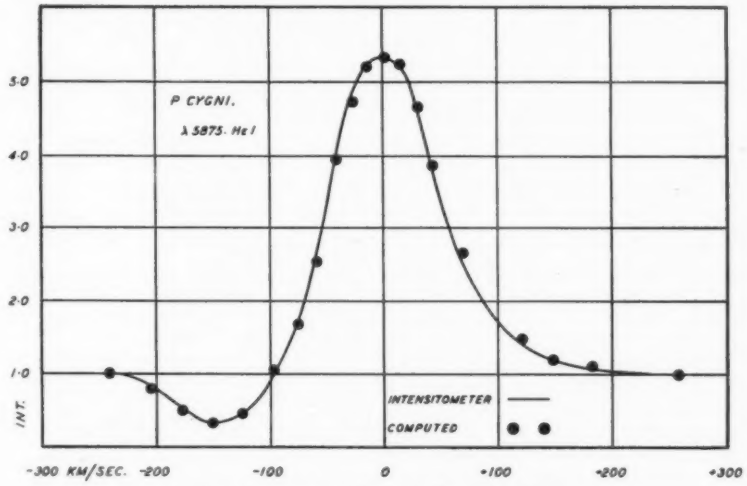

Fig. 3.—Intensity Record of λ 5875 HeI.

The differences between the two, as may be seen from Fig. 3, are no greater than would be expected from two successive measures of the same tracing. This is as predicted since there are no approximations involved in the theory of the machine and mechanically it is built to high precision standards. Numerous other spectral features measured with the intensitometer show excellent agreement with previous measures by other methods and two years of experience in its use have revealed no major flaws in its design and have led to few suggestions for its improvement.

Fig. 4 illustrates the accuracy with which the instrument will repeat a record of the same line. The two successive records shown are of the line λ4481 of Mg II in the spectrum of H.D. 223385. In this case the grain effect in the tracing has been reproduced in the intensity record instead of being averaged out as in Fig. 3. Such small differences as may be seen between the records are due to the fallibility of eye and hand in following the original tracing. A careful examination of the two profiles shows that the differences between them are inappreciable as compared to other sources of error in spectrophoto-

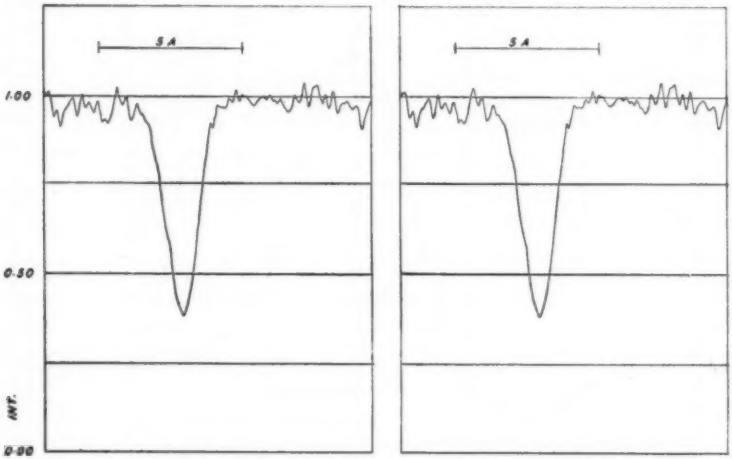

Fig. 4.—Successive Intensity Records of the Line λ 4481 Mg II in the Spectrum of H.D. 223385.

metric work. It may be noted that the co-ordinate system has been impressed on the record with the machine, using the same pen as that which drew the record.

Mechanical Rectification of the Spectrum

As suggested in the previous section, the "rectification" of line profiles by reducing the continuous spectrum to unit intensity can be performed quite rapidly with the aid of a transparent intensity scale and slide rule. However, in the case of certain late-type spectra with

large numbers of lines, it is desirable to have this done mechanically and a device has been worked out to do this but has not yet been incorporated in the machine. The principle is briefly as follows.

A calibration curve making use of logarithmic rather than direct intensities is drawn on the ground glass screen. A logarithmic tracing of the spectrum is then made and restricted to a strip of the paper five inches wide. This strip is then cut out and wound on the tracing transport mechanism instead of the original tracing. The tracing transport mechanism is altered in such a way that it can be moved bodily on ways backward and forward at right angles to the direction of motion of the tracing. An additional index is provided at right angles to the index shown in Fig. 1. A calibration curve is now drawn on the ground glass screen with logarithmic intensities as ordinates and direct intensities as abscissae. The ordinates of this curve are so adjusted that the new index in the axis of abscissae passes through the point in the curve corresponding to unit intensity.

The machine is then operated by two persons, one of whom as usual keeps the calibration curve and the tracing intersecting the vertical index at one point. The other operator moves the tracing transport mechanism bodily by means of a suitable handle and gears, in such a way that the line of the continuous spectrum always cuts the intersection of the two indices. The function of the second operator could of course be performed by a moving template cut to the shape of the continuous spectrum but it is doubtful whether this would be an improvement over manual operation. It is hoped at some future time to incorporate this feature in the instrument, and, as may be seen from Fig. 1, when it was originally built a portion of the edge of the base was machined square for the purpose. It is proposed to incorporate also two cutters in place of the two extra pens of Fig. 1, so that the five-inch wide strip will be cut automatically and accurately while the tracing is being made.

Dominion Astrophysical Observatory,
Victoria, B.C.
October 21, 1943.

A COMPARISON BETWEEN REFLECTORS AND REFRACTORS FOR PLANETARY WORK

By D. W. Rosebrugh

IN the November Journal Mr. E. K. White describes his experiments by which he slightly improved the definition of his reflector by forced ventilation of the tube.

The writer has recently experimented with another method of improving the definition of a reflector and has been able to compare the definition of the reflector, so adjusted, with that of a high class refractor of similar size, belonging to one of the active members of the A.A.V.S.O.

The writer has an old reflecting telescope with an 8¾-inch mirror of plate glass (not Pyrex) of 73 inches focal length, used as a Newtonian. An aluminized flat diagonal is used, as it is generally considered that a flat gives better definition than a prism diagonal. The telescope has a sheet-metal tube and an aluminum mirror cell. Thus the reflector violates many of the modern ideas for improved definition which call for a square plywood tube, with open corners around the mirror, giving good air circulation in the tube; a Pyrex mirror giving low temperature rate of expansion; and instead of a cell an open spider to which the mirror is clamped, giving good opportunities for the mirror to cool to air temperature.

When in use this reflector is opened for observing about an hour or more before observing is to start, so as to allow it to assume air temperature. For estimating variable stars fine definition is not needed, indeed some observers throw the image out of focus for comparison purposes, although the writer prefers to strive for good definition. Fourteenth magnitude stars have been seen with this instrument using a ½-inch Huyghenian Mogey eyepiece giving 150 power. This also was the lower limit of a 6-inch Clark refractor formerly owned by the writer.

When looking at planets the images at full aperture are unsteady. For planetary work the writer has found that the definition is greatly improved by the use of a 5¼-inch diameter cardboard diaphragm in front of the mirror. This covers the outer zones of the mirror which

may be distorted by unequal cooling of the mirror, but it is the writer's opinion that its beneficial effect is partly due to the elimination of the light rays passing down close to the wall of the tube, which presumably pass through air which is considerably cooled by the metal tube, and therefore striated. On one occasion when using the diaphragm a sharp gust of wind caused the image of Mars to expand into an agitated ball three or four times larger than the normal diameter, but the image promptly returned to normal when the wind dropped, which seemed to indicate that the trouble was striated air within the tube itself. The diaphragm also cuts down the objectionable brilliance of Mars, but a neutral filter at the eyepiece of the type called a "Venus" filter might suffice for this purpose.

It is interesting to compare the results achieved on Mars with this somewhat outmoded reflector using a 5¼-inch diaphragm with those obtained by others with high quality refractors. Parenthetically it may be said that they exceed anything formerly achieved by the writer with the 6-inch refractor that he formerly owned.

On December 5, 1943, at 9.15 p.m., E.S.T., the writer had an unusually good view of Mars, using a ¼-inch Huyghenian eyepiece giving 300 magnification. Margaritifer Sinus, Sabaeus Sinus and the pale grey areas on the southern half of the disc stood out like steel etchings, while Mare Acidalium was dimly visible in high northern latitudes. The canal Gehon which curves between Sabaeus Sinus and Mare Acidalium was seen momentarily about on the meridian of the planet. The writer had never seen any of these details before, though he had casually noted the presence of Margaritifer Sinus and Sabaeus Sinus on maps on previous occasions. The south polar Cap was not discernable.

Mr. Herbert M. Harris, 27 Victory Avenue, South Portland, Maine, kindly sent the writer a drawing of his view of Mars on November 29, 1943, at 9.00 p.m., E.S.T., made with his 6-inch F/5 Clark refractor, using a Huyghenian 0.4-inch eyepiece giving a power of 225. His drawing shows the same features as those sketched by the writer 6 days and 15 minutes later. On Mr. Harris's drawing these lie about 45° further east on the disc. This corresponds to the fact that in the 6 days and 15 minutes which elapsed between Mr. Harris's drawing and that made by the writer, Mars had turned on its axis

about 5.86 times or 50° less than 6 full turns. Hence Gehon which lies about 45° past the meridian in Mr. Harris's sketch was about on the meridian of Mars at the time of the writer's observation.

Mr. Harris did not notice the south polar Cap but this was seen by Mr. Herbert J. Hopkins, Old Orchard Beach, Maine, another member of the A.A.V.S.O. who was observing with Mr. Harris.

From these observations it appears that a reflector at reduced aperture will compare favourably for planetary work with a refractor of similar size, in moments of good seeing. It may be that with a refractor good seeing is obtained for a larger part of the time than with the writer's old reflector and it may be also that with a modern reflector with Pyrex mirror and good ventilation of the mirror and the tube, good seeing may be experienced for a larger proportion of the time than with the writer's reflector but the writer has no data with regard to these matters.

87 Fern Circle,
Waterbury 67,
Connecticut.

MONTREAL OBSERVATIONS AN OCCULTATION OF JUPITER

The following is our report of the occultation of Jupiter on January 13th.

Five of us gathered at the Ville Marie Observatory early on the Thursday morning—Dean Hall, DeLisle Garneau, J. E. Guimont, Francis P. Morgan and myself. Weather conditions were somewhat disappointing. The heavy clouds which had obscured the moon earlier in the morning had dispersed but there was a slight haze, and passing clouds at times interfered with observation. On the Society's 6-inch refractor we used a 110-power eyepiece. Outside the observatory we set up Mr. Garneau's 4-inch refractor with a 25-power eyepiece, and a 2½-inch refractor with a No. 3 eyepiece.

To Mr. Morgan had been assigned the particular task of watching for any distortion of Jupiter that might be due to traces of atmosphere as the moon neared the planet. The rest of us concentrated on the actual timing of the occultation. It had been hoped to record the occultations of the three moons of Jupiter as well as that of the planet itself, but the two smaller telescopes could not pierce the haze sufficiently to pick out the moons. Mr. Morgan, at the 6-inch, saw one only, presumably Io, the occultation of which we recorded at 48 minutes, 18.5 seconds after 7 a.m. (E.W.T.)

No matter how carefully we make our plans, something unexpected—and prosaic—usually upsets them. This time it was a clothesline pole a short distance from the observatory which at the exact moment of contact obstructed the view of the 6-inch telescope. So Mr. Morgan lost out on the first contact, but Mr. Guimont at the 4-inch and Mr. Hall at the 2½-inch called out simultaneously. Mr. Garneau and I were acting as time-keepers and recorders. I timed the first contact as 52 minutes 19 seconds while Mr. Garneau, equipped with a stop-watch, recorded it as 18.4 seconds and I willingly concede that his timing is probably the more accurate.

Less than a minute later heavier clouds made the two smaller telescopes useless, but the moon had moved sufficiently so that the pole was no longer an obstacle for the large telescope, and Mr. Morgan was able to observe the last contact which occurred at 53 minutes 42 seconds. The mean time of our two recordings, therefore, is 53 minutes, 0.2 seconds.

Unfortunately, at the time of reappearance the moon was obscured by clouds which even our largest telescope could not penetrate, but Mr. Hall was stationed at the 6-inch and I at the 4-inch in the hope that a break in the clouds might make a recording possible. When Mr. Hall caught his first glimpse of the planet at 19 seconds after 8.55 about one-quarter of the disk had already emerged. A few seconds later I caught a glimpse of it from my position but it was blotted out almost instantaneously.

Mr. Morgan reports that before the contact he saw no distortion of the

planet such as he had been looking for, but after the contact he noticed something entirely unexpected—a narrow blue band following the rim of the moon, separating it from the planet so that the planet appeared quite detached. Mr. Morgan offers the explanation that it might be due to mirage effect. The band, which was the colour of the sky, disappeared some time before the last contact, and upon comparing notes with the other observers, Mr. Morgan came to the conclusion that the clouds which had rendered the smaller telescopes useless had also blotted out the blue band, which confirms his belief that it was a mirage.

Mr. F. J. DeKinder, the treasurer of our Centre, was unable to be at the observatory that morning but he made an observation at his own home. Using his 4-inch refractor telescope, he recorded the first contact as 7.52 exactly.

This is a very lengthy report, but I thought you would be interested in all the details. We feel that we made our observations carefully, taking every precaution so that our report would be accurate. The watches used were checked with the Dominion Observatory time-signals on three consecutive days so that an adjustment could be made, if necessary, for any variation. The position of our observatory is calculated as Lat. 45° 28′ 22″ N, Long. 73° 37′ 18″ W, and that of Mr. DeKinder's home as Lat. 45° 36′ 34″ N, Long. 73° 40′ 38″ W.

This was the first occultation for which we, as a group, had made definite plans, but Mr. Garneau's enthusiasm is contagious and our programme now includes the recording of any occultations that can be observed with our telescopes. I promise you, though, that future reports will be more concise!

Isabel K. Williamson, *Recording Secretary.*

4504 Marcil Avenue,
Notre Dame de Grace,
Montreal, Que.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

The Atmosphere of Titan

Dr. Kuiper, using the excellent spectroscopic equipment of the McDonald Observatory, in Texas, has discovered the presence of an atmosphere on Titan. (Harvard Announcement Card 677). The gases detected are methane and possibly ammonia. This is the first spectroscopic, and perhaps the first incontrovertible evidence of the presence of an atmosphere on any of the twenty-eight satellites of our solar system.

Titan is the sixth satellite of Saturn in order of distance from the planet. It was discovered in 1655 by Huygens and is of about the eighth magnitude. With a probable diameter of 2600 miles, it is surpassed in size only by two of Jupiter's satellites, Ganymede and Callisto, and possibly by Neptune's satellite, Triton. Its mass has been computed as 1/4700 of that of Saturn, or one-fiftieth of that of the earth.

It is difficult to trace the history of the physical conditions of the planets and satellites with enough certainty to be able to quantitatively describe their present atmospheres. On the other hand, the dynamical theory of gases allows us to determine fairly simply whether the gravitational force on any object is high enough to prevent the escape of the molecules of an atmosphere under specified conditions.

The mean molecular velocity in a gas varies directly as the square root of the absolute temperature, and inversely as the square root of the molecular weight. In other words, high temperatures and light molecules are conditions for great speeds of the molecules; low temperatures and heavy molecules indicate slow molecular motion. The velocity of escape of a particle from a planet varies as the square root of the planet's mass divided by the square root of its radius.

In order to semi-permanently retain an atmosphere, the velocity of escape from the surface must be about five times the mean velocity of the molecules. The velocity of escape from the earth is 11.2 km. per sec.; from the moon (owing to its small mass), only about 2.4 km. per sec.; and from Titan 2.6 km. per sec. Thus the gravitational conditions on Titan are not markedly more favourable than those on the moon.

However, due to the great distance of Titan from the sun, the temperature is very low, possibly nearly two hundred degrees below zero Centrigrade. This will so decrease the velocities of the molecules that only hydrogen and helium would be light enough to move so rapidly that they could escape into space. Even the fairly light molecules of methane (CH_4, molecular weight, 16), and ammonia (NH_3, weight, 17) should be retained indefinitely at this temperature.

It will be recalled that the atmospheres of Saturn and Jupiter are characterized by methane and ammonia and those of Uranus and Neptune by methane. Thus Titan has the kind of atmosphere it theoretically should be able to retain and an atmosphere similar to that of its primary, Saturn. This new observation adds important information for the discussion of the development of the satellite systems.

The Faintest Star

Dr. Van Biesbroeck, also from McDonald Observatory, reports the discovery of the intrinsically faintest star known to date (Harvard Announcement Card 678). It is a companion to the 9th magnitude M star, H.D. 180617. It is separated from its primary by 74 seconds, corresponding to a distance of over ten times that of Pluto from the sun. The faint star is of apparent magnitude 18. Taking the distance of the system as six parsecs, the absolute magnitude of the star is nineteen. This is about 16 times fainter than the star Wolf 359, the faintest star previously known. The faint star radiates about 250 times as much light as our planet Jupiter, but only about a five hundred thousandth of the radiation of our sun.

F. S. H.

Back in Florida Once More

After four years filled with tragic happenings!

Many obstacles are now placed in the way of the Canadian citizen who wishes to go to the sunny south. In order to secure permission to enter the country of our friendly neighbours he must fulfil numerous (and reasonable) war-time conditions, while the Canadian customs officer makes sure that no one shall cross the border unless he bears the famous Form H of the Foreign Exchange Board.

No automobile jaunt this time; the railways at present are having their innings. Soon after the train started the ticket officials came

along. When a yard-long ticket was being produced one remarked to the other, "Florida", to which the passenger replied, "Yes, you're right." Next the U.S. officer appeared, examined the U.S. Consular documents and retained most of them. He passed on with a pleasant word. A little later, after he had looked once more over the "papers", he spoke to the traveller again and it was found that we had mutual friends—also that his son, although a citizen of the U.S.A., had been a graduate student at the University of Toronto and had been given the Ph.D. degree in the science of the earth at a recent convocation. Finally the Canadian officer paid his visit, took his share of the documents, including the writer's Registration Certificate, and wished the traveller a happy journey.

A stop-over of several days was made in Washington. Astronomers are surely the kindest and most hospitable people in the world. Many motor cars in the capital but not so many as four years ago. At the Naval Observatory there was evidence that the nation is at war. A barb-wire fence marks the circumference of "Observatory Circle" and a bar across the entrance to the grounds is removed only after pedestrians or the inmates of vehicles have been scrutinized closely. At night unwanted visitors would be received by armed guards and fierce watchdogs. Just within some of the buildings are shovels, axes, buckets, foot-pumps and supplies of water and sand. Evidently the city was considered vulnerable to an air attack—though no one fears an invasion now. The present writer was somewhat startled when he saw these precautions.

The visitor was pleased to greet many of his old friends and to make some new ones. The Superintendent of the Observatory, Captain Hellweg, is a busy man these days, and Captain Coleman is Assistant Superintendent. Dr. Eckert, the chief of the Nautical Almanac office, has new helpers in order to produce the indispensable computations demanded for operations on the land, on the sea and in the air. Dr. Morgan and Messrs. Watts, Burton, Wylie and Willis continue their fundamental observations and investigations. The very complete library, in charge of Mrs. Savage and Mrs. Bendigo, is kept as fully supplied with material and as efficient as is possible during these disjointed days.

The traveller reached "The Sunshine City" on January 24 and was told that the warm June-like weather apparently had come with

him, as heretofore there had been many overcast skies and much unpleasant temperature.

C. A. C.

The D.D.O. Machinist in the Navy

In November, Mr. Gerald F. Longworth, who for the past eight years has been observer-machinist at the David Dunlap Observatory, enlisted in the Royal Canadian Navy. After completing basic training in Toronto he has been transferred to the east coast as a naval artificer.

During the past four years much of the Observatory work in connection with constructing experimental instruments for the services has been carried on by Mr. Longworth. His other achievements included much of the machine work involved in building our auxiliary apparatus, such as a recording microphotometer, a blink microscope a projection measuring engine and the aluminizing equipment for the 74-inch reflector. His duties also included the maintenance of the observatory instruments and a great deal of observing.

F. S. H.

Two Years of Daylight Saving

The following editorial, taken from the *Edmonton Journal* of January 28, 1944, has been received from Professor J. W. Campbell:

Already the lengthening days remind us that even this far north we do "save daylight" by keeping our clocks set an hour faster than standard time. Just about two years have passed since daylight saving time went into effect in all parts of the dominion. The change was made on February 9, 1942.

Few complaints are heard now. The long dark mornings of mid-winter are still unpleasant, and it still does not seem right to start young children off for school in what is a good deal like "the middle of the night." But that dark-morning period is short and is about over now.

Nearly a year ago the Edmonton Chamber of Commerce was reported to have suggested to the city council that a study be made of the effects of daylight saving time, with special reference to this city in winter months. Nothing more has been heard of the matter, probably because everyone has become accustomed to fast time.

The tremendous difference in the impact of daylight saving in this northerly city is shown most simply by citing the mid-winter, equinoctial and mid-summer hours of sunrise and sunset. They are approximately as follows:

December 21—Sun rises 9:48, sun sets 5:16
March 21—Sun rises 7:35 and sets 7:50
June 21—Sun rises 5:04 and sets 10:07

So acceptable are the longer evenings in spring, summer and autumn in nearly all parts of the dominion that it would not be surprising if daylight saving were one of the war's changes to be retained permanently.

NEWTON'S PRISM AND STOURBRIDGE FAIR

Newton's famous spectrum experiment, 1668, was performed with a glass prism which he says he purchased at Stourbridge Fair, and reference to this Fair has been made in past issues of the JOURNAL. In Trevelyan's "English Social History" (p. 186), recently published, is further information about it, which our readers will be pleased to read:

> Cambridge was scarcely more famous for its University than for its Fair, held for three weeks in September on the stubble of the town fields, between the Newmarket road and the river. There North and South England exchanged goods, brought by land and water. Streets of booths were erected, where the North bought its hops and sold its wool and cloth. Traders from the Netherlands and the Baltic and great merchants of London did big business there in cloth, wool, salt-fish and corn. In days before the commercial traveller, fairs of this kind were essential to trade, and Stourbridge was the greatest in England: goods of every kind, wholesale and retail, were sold; housewives, thrifty and gay, came from far to furnish their houses or replenish their cupboards and to see "the fun of the fair". And there too were many of the farmers and half the bailiffs of East Anglia. The strange thing to our modern notions is that the jurisdiction over this vast annual hive of commerce lay with the University. Stourbridge Fair could not be begun till the Vice-Chancellor had come in full academic pomp and proclaimed it open.

C. A. C.

MEETINGS OF THE SOCIETY

AT VANCOUVER

October 12, 1943.—The first meeting of the year was held in the Science Building at the University of British Columbia. The speaker of the evening was Dr. William Petrie of the Physics Department of the University of British Columbia, and the subject "Planetary Nebulae".

The speaker pointed out that the early telescopic observers were startled to find small disk shaped formations that had the appearance of a planet. However, since these objects did not move relative to the background stars, it was realized that they could not be planets. The speaker showed a number of slides which illustrated the various forms of planetary nebulae that are found. The majority exhibit a pale green colour since the gaseous shell radiates chiefly in that part of the spectrum. In some of the planetaries, definite rings of brightness are present, indicating that physical conditions in the shell are far from homogeneous.

A central star is not observed in all of the planetaries, which suggests that the "missing stars" are too hot to be observed. A high temperature source radiates chiefly in the ultra-violet, and this radiation is not in the visible region of the spectrum.

The speaker then discussed some of the more interesting statistics concerning the planetaries. They are rare objects in the astronomical world, extremely distant, large in volume and small in mass. The large volume and resulting low density accounts for the interesting spectra of these objects. For many years the origin of certain lines in the spectra of the planetaries was unknown, and the possible new element was called "nebulium". We now know that these lines arise from ordinary elements under the special conditions existing in the low density shells. The brightness of a planetary is too great to be ascribed to reflected radiation from the central star. The explanation is that radiation of short wave-length in the invisible part of the spectrum is absorbed and re-emitted in stages in the visible part of the spectrum.

At the conclusion of the lecture considerable discussion took place regarding the physical principles explained during the evening.

November 9, 1943.—The speaker of the evening was Lt.-Commander C. A. McDonald, R.C.N.R., and his subject "Straight Lines and Circles in Navigation". The speaker took the audience on an imaginary coastal trip, and explained the various pilotage problems that the navigator must consider.

He first discussed the method of obtaining a fix by laying down two lines of bearing. A fix may also be obtained from a single line of bearing and a distance. A useful method of obtaining distance involves the height of an object when it first becomes visible. The speaker explained the method of sailing

through danger areas by means of the so-called "danger angle". Radio devices are now of great aid to the coastwise navigator.

Certain phases of celestial navigation were discussed briefly. The speaker showed how a noon sight of the sun to determine altitude, and a knowledge of the declination of the sun could be combined to give the latitude of the observer. The determination of longitude is a more complex problem. It is easily determined, of course, if the ship carries a clock giving Greenwich time, but longitude is usually determined from sextant sights on the sun. A single value of the sun's altitude places the observer on a large circle called the "Sumner Circle". In most cases this circle is so large that it can be replaced by a short tangent drawn to the circle. A second reading of the sun's altitude gives another line and the intersection of the two yields a fix.

There was considerable discussion at the end of the lecture, and great interest was shown by members of the Air Force who attended.

December 14, 1943.—The speaker of the evening was Dr. R. M. Petrie of the Dominion Astrophysical Observatory, and the subject "Moving Star Clusters". The speaker first discussed the various types of clusters that are found in the universe and suggested that moving and galactic clusters are essentially the same. These moving clusters are extremely useful, since a study of the members of the cluster yields accurate information concerning the parallel axes of the stars. The speaker explained how radial velocities and proper motions are combined to give a true picture of a star's motion.

Some interesting diagrams showed the changes that will take place in several moving clusters in the future. Star clusters are subject to a number of disintegrating forces and will hold together for a finite time only. Discussion after the lecture was chiefly of a philosophical nature and dealt with such topics as the entropy of the universe, and the time of relaxation of stellar systems.

WILLIAM PETRIE, *Recorder.*

AT EDMONTON

November 11, 1943.—The president called the meeting to order at 8.25 p.m. It was reported that the key map of the moon's surface was framed and ready to hang beside the model in the new Observatory.

The following were elected members of the Society:—

Mr. and Mrs. G. Milner, 10613—98 Ave.
Mr. S. F. Page, 11121—88 Ave.
Mr. and Mrs. L. Desjardins, 9132—77 Ave.
Mr. H. A. Macgregor, Normal School.

The president appointed the following nominating committee to bring a report to the annual meeting: Dr. Campbell, Mr. K. Angus, and Mr. W. A. McAulay.

The HANDBOOK talk was given by Mr. Wates. Interest at present is

centered around the planets, especially in the eastern sky before morning twilight. Some drawings of Saturn were shown as a guide telling what to look for through the telescope.

Mr. G. W. Robertson presented some statistical results worked out for the past five years on the number of good, bad, and indifferent nights for astronomical observations, in the Edmonton district.

The main paper of the evening was given by Mr. Max Wyman on "The Tides". This is a periodic rise and fall in the ocean level, which varies in time and amount for every port and for every day. Primitive explanations are based on magic or religion. Newton gave the first serious theory. The simplest facts to be explained are: (1) successive high waters are 12½ hours apart, (2) the amount of rise is variable, (3) when the declination of the moon is zero the two tides in a given day are approximately equal. The primary mechanical cause of tides must be some combination of centripetal forces, centrifugal tendencies, due to the rotation of the earth-moon system. These produce resultant tide-raising forces on the particles of the earth, both towards and away from the moon, but the particle forces balance over the earth as a whole. Complications are added by taking into account the effect of the sun, the rotation of the earth on its axis, variations in ocean depth, and the disposition of the continents. There is even now no complete quantitative theory. A tidal chart for one port is obtained by theory helping long continued observation to predict the future behaviour of the waters.

Some of the speakers taking part in the discussion went back to naive primitive explanations. Others gave a different point of view which, however, essentially agreed with the speaker. The groaning of ice in Great Bear Lake might be due to tides, or to earth stresses.

E. H. Gowan, *Honorary Secretary.*

The Royal Astronomical Society of Canada

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